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INFLUENCE OF POPULATION DENSITY ON THE CHOICE OF TECHNOLOGICAL SOLUTIONS FOR URBAN WASTEWATER TREATMENT

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Abstract

The article examines the impact of population size on the choice of technological solutions for the treatment of urban wastewater (UW). It analyzes the factors that determine the specific challenges of wastewater management in cities of different sizes, including the volume and composition of wastewater, regulatory requirements for the quality of treated water, and economic constraints. Based on a comparative analysis, the article provides recommendations for selecting optimal technological schemes and equipment for cities with different populations, ensuring the achievement of required environmental performance and economic efficiency.

Keywords: Wastewater treatment municipal wastewater, population size, technological solutions, biological treatment, mechanical treatment, economic efficiency, wastewater disposal.

Introduction

Municipal wastewater treatment is a critical undertaking for ensuring environmental safety, safeguarding public health, and conserving water resources. The design of a wastewater treatment process (WWTP) takes into account various factors, including wastewater volume, the composition of pollutants, climatic conditions, required effluent quality, and economic feasibility. City population size is a crucial determinant in the selection of appropriate technological solutions.

Large cities with populations exceeding one million inhabitants (metropolises) are characterized by substantial wastewater volumes, complex pollutant compositions, high building density, and limited land availability for the siting of wastewater treatment plants (WWTPs). Smaller cities with populations under one million typically exhibit lower wastewater volumes, simpler pollutant profiles, and greater flexibility in selecting treatment technologies.

Objective and Research Tasks

The objective of this study is to analyze the correlation between the population size of urban settlements and the selection/development of modern technologies, considering criteria such as economic efficiency, environmental safety, and compliance with regulatory requirements. Furthermore, the research aims to analyze the influence of city population size on the selection of optimal technological solutions for urban wastewater treatment. To achieve this objective, the following tasks will be undertaken:

Analysis of factors that determine the specific challenges of wastewater management in cities with varying population sizes.

Comparative analysis of technological solutions for the treatment of municipal wastewater (MWW) employed in cities of different scales.
Evaluation of the economic effectiveness of various technological solutions as a function of city population size.
Development of recommendations for selecting optimal technological schemes and equipment for cities with varying population sizes.

Factors Determining the Specificity of Wastewater Management in Cities with Varying Population Sizes The selection of technological solutions for the treatment of municipal wastewater (MWW) is determined by a complex set of factors, among which the city's population size plays a crucial role. The main factors related to city population size are:
Wastewater Volume: Directly proportional to the city's population, determining the capacity of wastewater treatment plants (WWTPs). In large cities, not only does the overall volume increase, but also its daily and hourly variability, placing specific demands on WWTPs.
Wastewater Composition: In larger cities, the composition of wastewater is more complex and diverse, containing a greater quantity and concentration of organic pollutants, nutrients, and specific industrial contaminants. This is due to more developed industry and a wider variety of economic activities.
Effluent Quality Requirements: Larger cities typically have more stringent requirements for effluent quality, especially in cases where discharge occurs into water bodies used for drinking water supply or recreation.
Economic Constraints: The cost of construction and operation of WWTPs increases significantly with increased capacity and stricter effluent quality requirements. Therefore, the selection of technological solutions must consider economic feasibility and funding availability.
Territorial Constraints: In large cities, land for WWTPs is limited, requiring the use of compact and high-performance technologies.
Energy Efficiency and Environmental Safety: Modern requirements necessitate the selection of solutions that reduce energy consumption and minimize negative environmental impacts, including reducing greenhouse gas emissions and managing waste (sludge).
Comparative Analysis of Technological Solutions for the Treatment of Municipal Wastewater (MWW)
Currently, various technological solutions are used for the treatment of MWW, including mechanical, biological, and physicochemical treatment, as well as advanced treatment and sludge management.
Mechanical Treatment: Regardless of city population size, mechanical treatment is a mandatory step in MWW treatment. It includes screening on bar racks, grit removal in grit chambers, and sedimentation in primary clarifiers. However, the size and quantity of equipment for mechanical treatment vary significantly depending on the WWTP capacity. In large cities, more advanced designs of bar racks and grit chambers are used to ensure more efficient removal of large and small particles.

Biological Treatment: Biological treatment is the main step in removing organic pollutants and nutrients. The selection of biological treatment technology depends on the city population size, wastewater composition, and regulatory requirements.

In small cities (up to 100,000 inhabitants), simple and economical technologies are often used, such as extended aeration activated sludge systems, trickling filters, and stabilization ponds.

In medium-sized cities (100,000-500,000 inhabitants), activated sludge systems with various flow configurations are used, as well as modern modifications of trickling filters. Membrane bioreactors (MBRs) may be used to increase treatment efficiency.

In large cities (over 500,000 inhabitants), high-performance and compact technologies are used, such as MBRs, activated sludge systems with nitrification-denitrification, and biological phosphorus removal. Combined schemes combining various biological treatment technologies are also possible.

Advanced Treatment: Advanced treatment is necessary to achieve high effluent quality requirements. Filtration (sand, carbon, membrane filters), adsorption, ozonation, ultraviolet (UV) disinfection, and other methods are used as advanced treatment methods. The choice of advanced treatment method depends on the required degree of treatment and specific pollutants in the wastewater. In large cities, membrane filtration and UV disinfection are widely used to ensure high effluent quality.

Sludge Management: Sludge management includes thickening, stabilization, dewatering, and disposal. In large cities, where a large amount of sludge is generated, modern technologies are used, such as anaerobic digestion, aerobic stabilization, thermochemical treatment, and incineration. Anaerobic digestion allows the production of biogas, which can be used for energy production.

Economic Efficiency

Economic efficiency is an important criterion in selecting technological solutions for MWW treatment. Both capital (CAPEX) and operational (OPEX) expenditures must be considered.

Capital Expenditures (CAPEX): Depend on the cost of equipment, construction and installation work, and design work. In large cities, where more complex and expensive technologies are used, capital expenditures are significantly higher than in small cities.

Operational Expenditures (OPEX): Include costs for electricity, reagents, equipment maintenance, and personnel salaries. In large cities, where high-performance technologies are used, operational expenditures are also typically higher. For the economic efficiency, it's necessary to conduct/perform a whole life analysis (LCA), considering the analysis must consider all costs and benifits relation to the construction and operation of OS.

Recommendations for Selecting Optimal Technological Schemes

Based on the analysis conducted, the following recommendations can be formulated for selecting optimal technological schemes for MWW treatment depending on city population size:

Small Cities: Mechanical treatment: bar racks, grit chambers, primary clarifiers. Biological treatment: extended aeration activated sludge systems, trickling filters, or stabilization ponds.

Advanced treatment: sand filters, UV disinfection. Sludge management: thickening, stabilization, dewatering on sludge drying beds.

Medium-Sized Cities: Mechanical treatment: bar racks, grit chambers, primary clarifiers. Biological treatment: activated sludge systems with various flow configurations, modern trickling filters, or MBRs. Advanced treatment: sand, carbon, or membrane filters, UV disinfection. Sludge management: thickening, stabilization, dewatering on centrifuges or belt filter presses.

Large Cities: Mechanical treatment: automated bar racks, aerated grit chambers, primary clarifiers with scum removal. Biological treatment: MBRs, activated sludge systems with nitrification-denitrification and biological phosphorus removal. Advanced treatment: membrane filtration, adsorption, ozonation, UV disinfection. Sludge management: anaerobic digestion with biogas production, aerobic stabilization, thermochemical treatment, incineration.

Conclusion

Population size has a significant influence on the selection of technological solutions for the treatment of municipal wastewater. In large cities, where wastewater volumes are large and effluent quality requirements are high, more complex and expensive technologies must be used, ensuring a high degree of treatment and waste utilization. In small cities, simpler and more economical technologies can be used, ensuring that required environmental performance is achieved at minimal cost.

The selection of an optimal technological scheme for MWW treatment should be based on a comprehensive analysis of the factors that determine the specific wastewater management challenges in each particular case, and should consider not only environmental and economic efficiency but also social aspects. The development of new wastewater treatment technologies, such as nanotechnology and biotechnology, opens up new perspectives for increasing the efficiency and sustainability of wastewater management systems.

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